

Charge asymmetries in charm photoproduction ^{*}

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Abstract

Charm quarks are expected to be produced mainly by the photon-gluon fusion mechanism in $\gamma - N$ interactions. However, a small part of the total charm cross section originates in similar processes to those appearing in charm hadroproduction through the resolved (hadronic) component of the photon. Although the contribution of the resolved part of the photon is small at fixed target energies, it can help to understand the small but sizeable charge asymmetries measured in charm hadron photoproduction experiments.

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1 Introduction

Charm hadrons in photon nucleus interactions at typical fixed target experiment energies, are expected to be produced predominantly by photon-gluon fusion followed by fragmentation.

As c and \bar{c} quarks in the $\gamma g \rightarrow c\bar{c}$ process are produced at the same rate, apart from a tiny \bar{c} excess appearing from Next to Leading Order (NLO) contributions [1], the final charm hadron and anti-hadron cross sections should be approximately the same. Furthermore, associated production, which together with Leading Particle Effects (LPE) has been observed to play an important role in the hadroproduction asymmetries for charm and anti-charm particles [2, 3]. This should not induce charge asymmetries in photoproduction since the effects are the same for particles than for anti-particles within this scheme.

However, the SLAC Hybrid Photon Facility Collaboration [5] has reported a noticeable charge asymmetry in meson photoproduction. This result has been confirmed more recently by the E691 [6] and the E687 [7] charm photoproduction experiments. Actually, the E687 Collaboration presented results on charge asymmetries in D^-/D^+ and D^{*-}/D^{*+} photoproduction which are consistent, at a three sigma level, with a positive asymmetry. Results on D_s^-/D_s^+ , \bar{D}^0/D^0 and even Λ_c^+/Λ_c^- photoproduction asymmetries, from both the E687 and the E691 experiments, are less clear since the error bars are still large to be conclusive, but all these measurements seems to indicate a small charge asymmetry (See Table 1 for a summary of the E687 and E691 results).

The origin of the charge asymmetry in photoproduction remains unexplained. However, in Ref. [5], a simple model which qualitatively might account for the observed results has been presented. In this simple model, a charge asymmetry arises when a light anti-quark (\bar{u} or \bar{d}) in the photon structure annihilates with a quark of the same flavor from the nucleus in the process $q\bar{q} \rightarrow q'\bar{q}'$, favoring thus the production of a particle containing the accompanying quark from the photon liberated in the interaction. This mechanism is twofold. On one side an asymmetry appears in the particle / anti-particle production due to the different content of quark and anti-quarks in the target nucleons and, on the other side, an asymmetry between final particles containing u or d valence quarks should arises because of the different content of u and d valence when targets are made of a different number of protons and neutrons.

Particle	Decay mode	R (E691) [6]	R (E687) [7]
D^0	$K^-\pi^+$	1.08 ± 0.03	1.04 ± 0.03
	$K^-\pi^+\pi^+\pi^-$		1.04 ± 0.03
D^+	$K^-\pi^+\pi^+$	1.04 ± 0.3	1.08 ± 0.02
D^{*+}	$D^0\pi^+$	1.15 ± 0.07	1.13 ± 0.03
	$(D^0 \rightarrow K^-\pi^+)$		
D^{*+}	$D^0\pi^+$	1.23 ± 0.07	1.08 ± 0.04
	$(D^0 \rightarrow K^-\pi^+\pi^+\pi^-)$		
D_s^+	$\phi\pi^+ + \bar{K}^{*0}K^+$		0.92 ± 0.14
	$K^-K^+\pi^+$		0.95 ± 0.09
Λ_c^+	$pK^-\pi^+$	0.79 ± 0.17	0.93 ± 0.14

Table 1: R = antiparticle/particle ratio. The D^+/D^- was the statistically most significant sample of the E691 experiment (they saw a raw signal of 4864 ± 103 events, see Ref. [6]). Results of the E687 Collaboration were taken from Ref. [7].

In Ref. [7] a model based on the Lund-string fragmentation scheme is presented. In the model the color field between the target diquark and the charm quark produced in the photon-gluon interaction build a string. Similarly the bachelor quark build a string with the anticharm quark. The model is discussed there and further details can be found in Ref. [8]. A very good agreement with experimental data is obtained with the two versions describe there.

Here we try to understand the observed asymmetry in terms of the effects introduced by the resolved component of the photons.

2 Charm photoproduction cross sections

The invariant cross section for the photoproduction of a heavy quark is as follow [1]

$$\frac{Ed^3\sigma}{dp^3} = \sum_i \int dx \frac{Ed^3\hat{\sigma}_{\gamma i}}{dp^3} f_i^H(x) + \sum_{i,j} \int dx_1 dx_2 \frac{Ed^3\hat{\sigma}_{i,j}}{dp^3} f_i^\gamma(x) f_j^H(x) . \quad (1)$$

In eq.(1), a μ dependence is implicit in the elementary cross sections $\hat{\sigma}$ and the number densities of light partons (gluon, light quarks and anti-quarks)

in the hadron ($f_i^H(x)$) and the photon ($f_i^\gamma(x)$). The short distance cross sections $\hat{\sigma}$ are calculable as a perturbative series in $\alpha(\mu^2)$.

The first term in the right hand side of eq.(1) known as point like contribution, while the second term is the hadronic component of the photon. The separation of the two terms is controlled by the scale μ (see Ref. [1] for a detailed discussion).

Typical contributions to the first term of eq.(1) are

$$\begin{aligned}
\gamma + g &\rightarrow c + \bar{c} \\
\gamma + g &\rightarrow c + \bar{c} + g \\
\gamma + q &\rightarrow c + \bar{c} + q \\
\gamma + \bar{q} &\rightarrow c + \bar{c} + \bar{q}
\end{aligned} \tag{2}$$

where the first process receives contributions from Leading and Next to leading order while the second and following appear only at NLO. To this order in the perturbative series of the point like photon coupling, a tiny difference arises in the c and \bar{c} cross sections. However, this effect is very small to account for the observed asymmetries in charm meson photoproduction.

The partonic subprocesses contributing to the resolved photon component up to NLO are

$$\begin{aligned}
g + g &\rightarrow c + X & g + g &\rightarrow \bar{c} + X \\
g + q &\rightarrow c + X & g + q &\rightarrow \bar{c} + X \\
g + \bar{q} &\rightarrow c + X & g + \bar{q} &\rightarrow \bar{c} + X \\
q + \bar{q} &\rightarrow c + X & q + \bar{q} &\rightarrow \bar{c} + X
\end{aligned} \tag{3}$$

where X is either a c quark (anti-quark) or a c quark (anti-quark) plus a gluon. All these terms receive contributions from both Leading and Next to Leading Order (see Ref. [9]). Again, at NLO a tiny excess of \bar{c} over c quarks appears.

The convolution of the differential cross section $d\sigma/dx_F$ for charm quark production with the Peterson fragmentation function

$$D_{c/H_c}(z) = \frac{N}{z \left[1 - \frac{1}{z} - \frac{\epsilon}{1-z}\right]^2}, \tag{4}$$

gives a good description of the main features of D° and \bar{D}° photoproduction with $\epsilon = 0.11$, and D^\pm photoproduction with $\epsilon = 0.09$ (See Fig. 1). However,

as fragmentation is the same for c than for \bar{c} , no further asymmetries than those already appearing from the NLO calculation of heavy quark production arise in the final hadronic state.

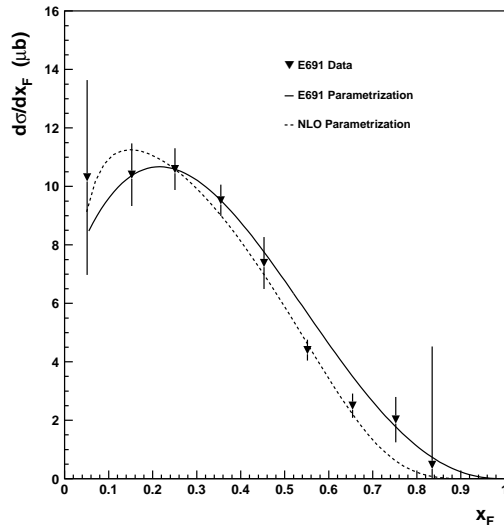


Figure 1: D^0 and D^\pm differential cross sections as a function of x_F compared to experimental data from the E691 Collaboration [6]. For the NLO parametrization we have used GRV-LO and GRVG-LO [4] parton distribution functions for hadron and photon respectively.

3 The hadronic contribution of the photon

The hadronic contribution to the total cross section of eq.(1) can produce additional contributions to the charm hadron production asymmetry *via* the mechanism outlined in Ref. [5]. When a resolved photon interacts with a nucleon in the target, the process $\bar{q}_\gamma q_N \rightarrow c + \bar{c}$ is favored over the process $q_\gamma \bar{q}_N \rightarrow c + \bar{c}$ due to the partonic structure of nucleons. Then an excess in the production of mesons containing a c over mesons containing a \bar{c} quarks arises at the hadronization level. This is due to the fact that the produced \bar{c} quark can recombine easily with the q_γ liberated in the collision to produce an anti-meson in the final state. The recombination of the c quark with the q_γ should instead produce a baryon. This mechanism tends to produce more charm anti-mesons than mesons and, conversely, more charm baryons

than anti-baryons, as the experimental data seems to indicate. D_s^\pm meson photoproduction should not present any asymmetry at all since $s = \bar{s}$ in both the nucleon and the photon. Fig. 2 shows a pictorial representation of the model.

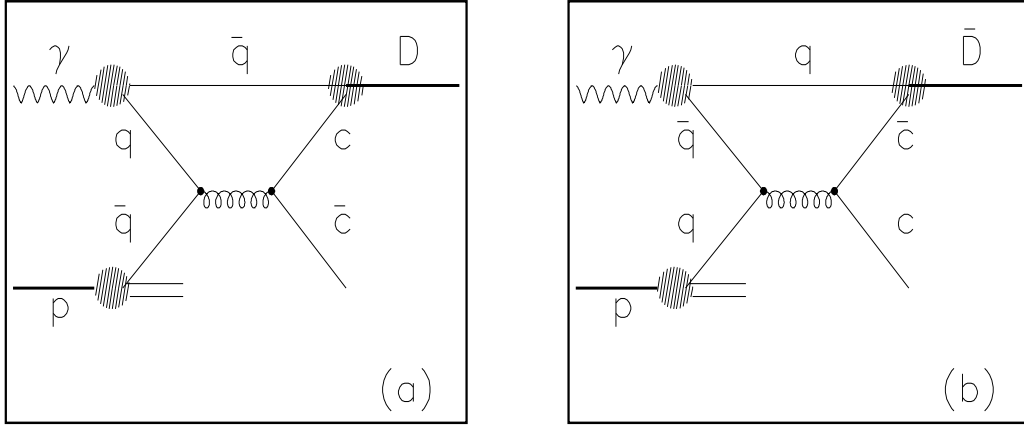


Figure 2: Production of charm mesons and anti-mesons in the model. The cross section of the process in (a) must be smaller than the one in (b) just because antiquarks density in photons is smaller than quarks densities.

Furthermore, as the proton has two u and one d valence quarks, the production of \bar{D}^0 ($u\bar{c}$) should be favored over the production of D^- ($d\bar{c}$) in $\gamma - \text{proton}$ interactions. The opposite must happen in $\gamma - \text{neutron}$ interactions. Notice also that, as the results obtained by the E691 and E687 Collaborations are on γ -Beryllium interactions, and since the Beryllium nucleus has more neutrons than protons, and excess of D^- over \bar{D}^0 should appear. Although none of the above experiments have measured the D^-/\bar{D}^0 asymmetry, predictions of the model seems to agree with the experimental data as long as the anti-particle to particle ratio is bigger for D^-/D^+ than for D^-/\bar{D}^0 . Notice that the ratio D^+/D^0 should be approximately one, independently of the target particle since production in the forward ($x_F > 0$) region in these cases should proceed mainly through independent fragmentation of the c quark.

The hadronization of the perturbatively produced c (\bar{c}) quark through the recombination with the debris of the photon can be calculated along the lines

developed in Ref. [10]. However, the recombination processes are not easy to be quantitatively estimated. On one hand, the momentum correlation between the perturbatively produced $c(\bar{c})$ quark and the fragments of the photon must be accounted for and, on the other hand, there exist an inherent difficulty associated with the definition of the multi-quark distribution and the recombination function within this scheme.

Nevertheless, as the recombination process should not enhance the already present asymmetry, it is still possible to make some quantitative estimates which we shall present in the next section.

4 Estimation of charge asymmetry from recombination

In order to make a quantitative estimate of the charge asymmetry induced by diagrams in Fig.(2), we define

$$A = \frac{\sigma_{q\gamma\bar{q}_p} - \sigma_{\bar{q}\gamma q_p}}{2\sigma_{\gamma g} + \sigma_{H p}} \quad (5)$$

where

$$\sigma_{\bar{q}\gamma q_p} = \sum_{i,j} \int dx_1 dx_2 \bar{q}_i^\gamma(x_1) q_j^p(x_2) E \frac{d^3\hat{\sigma}_{i,j}}{dp^3} \quad (6)$$

$$\sigma_{q\gamma\bar{q}_p} = \sum_{i,j} \int dx_1 dx_2 q_i^\gamma(x_1) \bar{q}_j^p(x_2) E \frac{d^3\hat{\sigma}_{i,j}}{dp^3} \quad (7)$$

are the cross sections for the production of a $c - \bar{c}$ pair from light quark anti-quark annihilation. In eq.(6) the anti-quark comes from the photon while in (7) it originates in the proton structure.

$\sigma_{\gamma g}$ is the point like contribution to the total cross section of Eq.(1) and $\sigma_{H p}$ is the sum of the cross sections of Eqs.(6), (7), and the gluon-gluon fusion processes appearing in the resolved photon contribution.

As the separation of the resolved and point like contributions to eq.(1) is controlled by the factorization scale entering in the photon and proton parton distributions, we have calculated the asymmetry defined by eq.(5) for $\mu_F = 1; 2$ GeV. The renormalization scale has been also varied according to $\mu_R = a m_c$ with $m_c = 1.2; 1.5; 1.8$ GeV and $a = \frac{1}{2}; 1; 2$. The individual

contributions of each process entering in eq.(5) are plotted as a function of the incident photon energy for $\mu_F = \mu_R = m_c$ in Fig. 3, the GRV-LO and GRVG-LO parton distribution functions have been used for calculations.

The c/\bar{c} asymmetry appearing from NLO contributions to eq.(1) is displayed in Fig. 4 for a γ energy of 200 GeV, the GRV-LO and GRVG-LO parton distribution functions were used. At this energy, the ratio of the c to the \bar{c} cross sections is 1.006, which is smaller than the D/\bar{D} cross sections ratio measured in experiments (See Table 1), but within errors compatible with the more recent measurements of the E687 experiment.

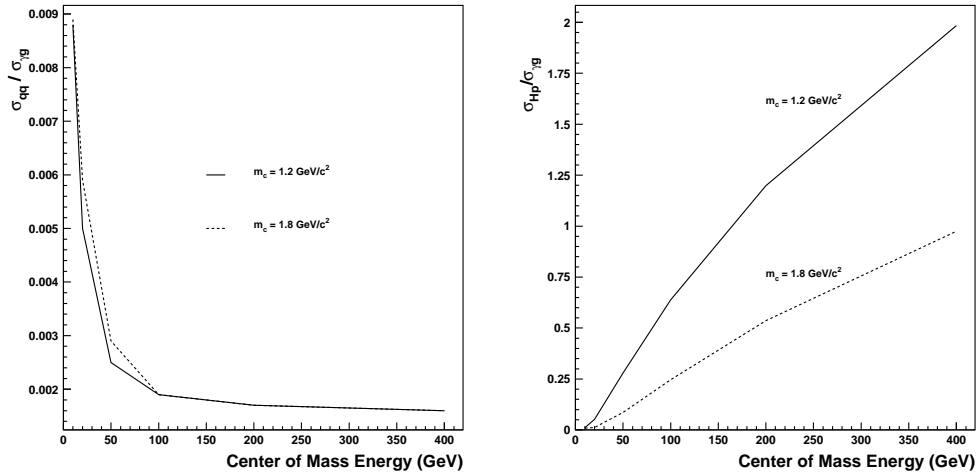


Figure 3: Contribution of each process to the total cross section for charm photoproduction as a function of the incident photon energy. σ_{qq} represents the $\bar{q}_\gamma q_p$ and $q_\gamma \bar{q}_p$ processes.

As can be seen in Fig. 3, the $\bar{q}_\gamma q_p \rightarrow c + \bar{c} + X$ and $q_\gamma \bar{q}_p \rightarrow c + \bar{c} + X$ become less important as the photon energy rises up, indicating that any charge asymmetry arising from the resolved photon component must decrease with the photon energy, E_γ .

5 Conclusions

We have tried to explain the observed charge asymmetry in photoproduction experiments using the resolved component of the photon. We have found

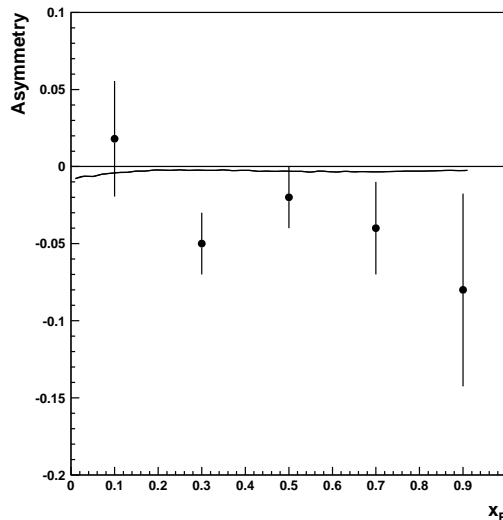


Figure 4: Total charge asymmetry. Dots represent experimental data from E687 [7]. The curve is the c/\bar{c} asymmetry as a function of x_F from NLO contributions, eq.(5), in $\gamma - p$ interactions for a 200 GeV energy beam.

that even when this part is small for typical fixed target energies the charge asymmetry raised from recombination is within errors consistent with the more recent measurements of E687. The model of ref. [7, 8] gives a larger asymmetry than our approach but given the accuracy of experimental data it is still hard to be conclusive on the responsible production mechanism. We expect that E831/FOCUS [11] with its one million of charm reconstructed candidates shed light on the issue.

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